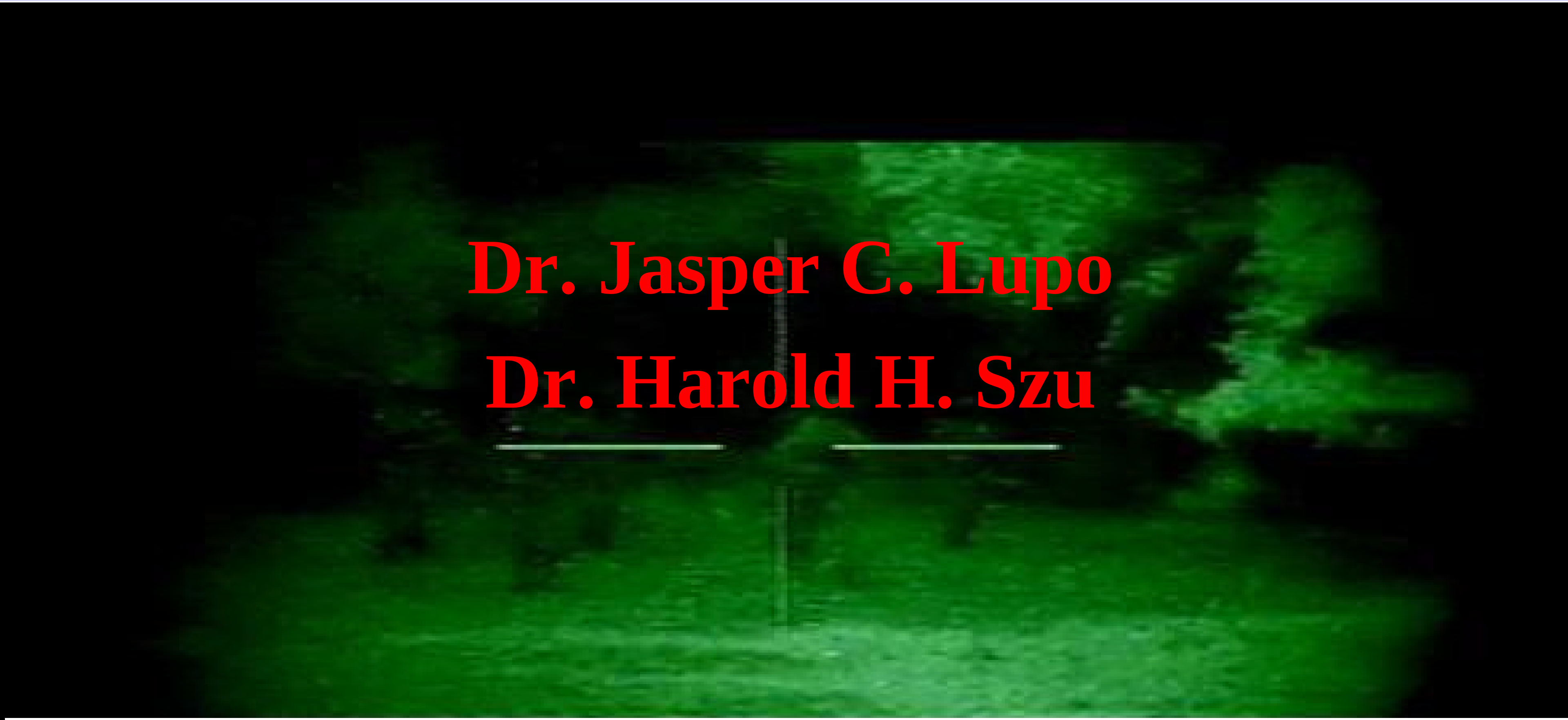
Smart Sensor Web on Power Line for Urban Defense



Dr. Jasper C. Lupo

Dr. Harold H. Szu

Night Operation Symposium, New Orleans,

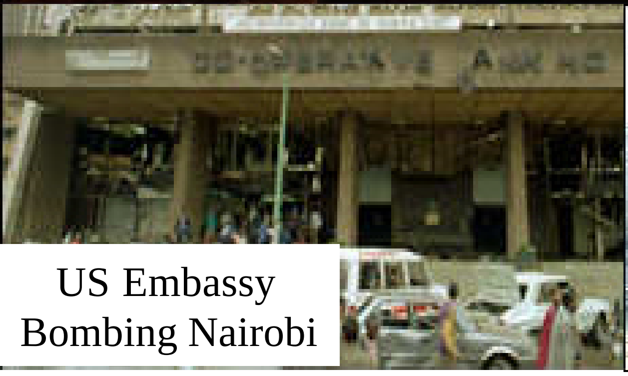
Mar 14, 2002

Asymmetric Warfare: Terrorist Attacks

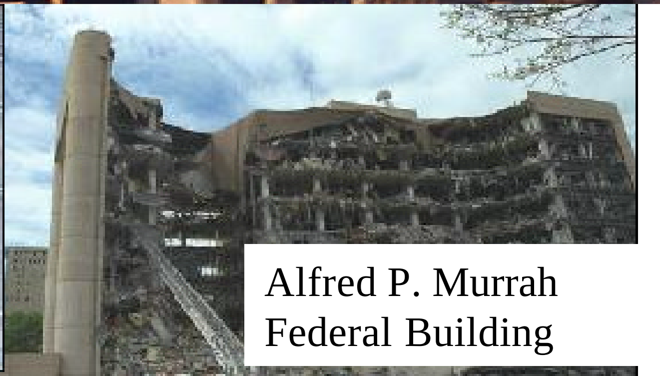

Tokyo Victims
Nerve Agent


US Marine
Donning
Gas Mask


Kurdish Victim
Mustard Agent

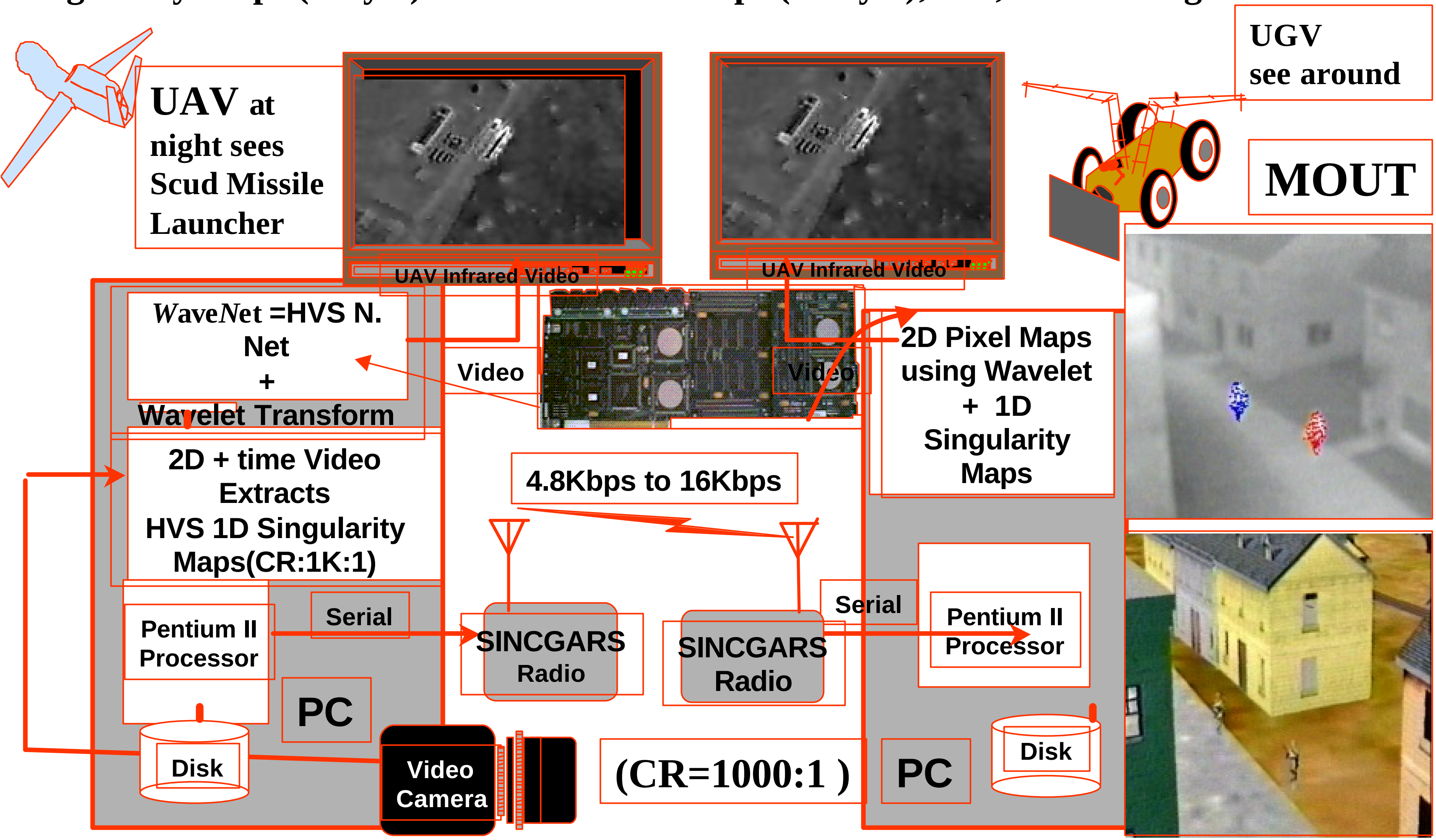

US Embassy
Bombing Nairobi


USS Cole


Alfred P. Murrah
Federal Building

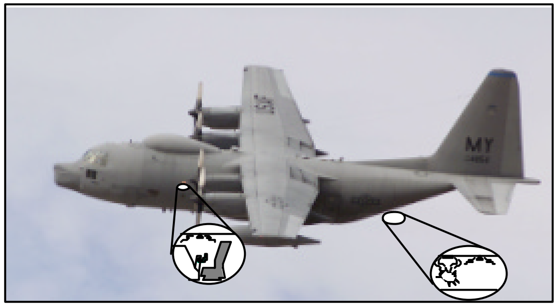
Smart Sensor Web (SSW)
Feature Preserving Image Compression

Video Com is demonstrated using human visual sys. (HVS) in correlating 1D Singularity Maps (k Byte) rather 2D Pixel Maps (M Byte); Szu, J. Ele. Imag. 1998



Joint Chemical Agent Detector Operational Mission Profiles

LONG TERM-LOW DOSE MONITORING OF CRITICAL SHIP COMPARTMENTS



INTERIOR DETECTION LOW-DOSE ALARM

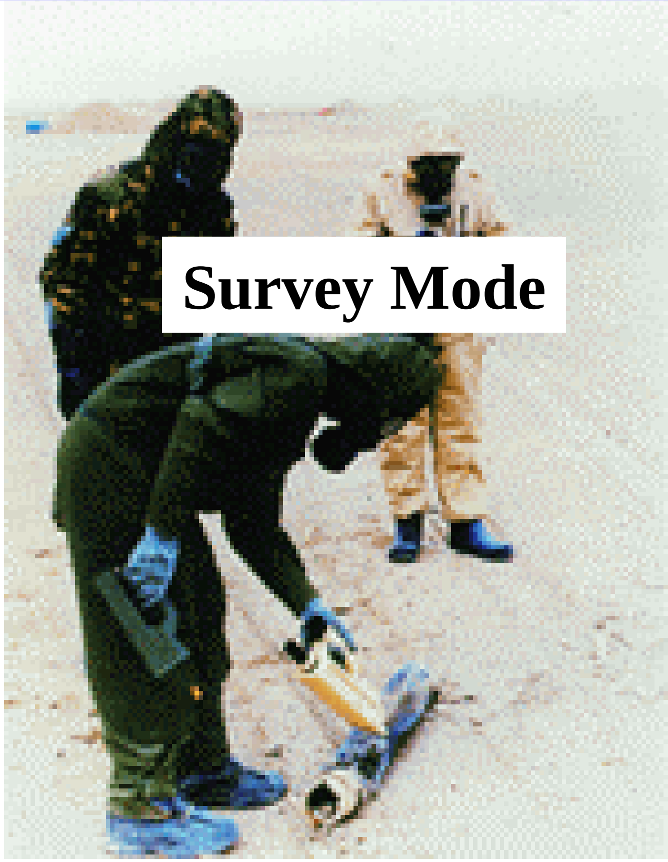
US Government Quantities

- **US Army 230,000**
- **US Air Force 22, 015**
- **US Marine Corps 15,485**
- **US Navy 2,500**

DETECTION TO CHECK FOR CONTAMINATION WHILE LOADING

PERSONAL DETECTOR

What Are Desirable Detector Features For Real-World Dynamic Conditions?



(1) Selectivity, (2) Sensitivity, (3) Speed,
(4) Size, (5) Cost, (6) Power,
(7) Robustness, (8) RH/T, (9) Baseline

Chemical Biological Terrorist Alert Broadcast System(CBTABS)

Concept/Use: Foreign and domestic bio-terrorism represents an increasing threat to our national security of deliberate releases of infectious agents. Early detection and response are critical to integrate microbial detection sensors with nanotechnology, high speed networks, and distributed artificial intelligence to detect a potential outbreak, identify the offending agent(s), and disseminate alerts to appropriate parties.

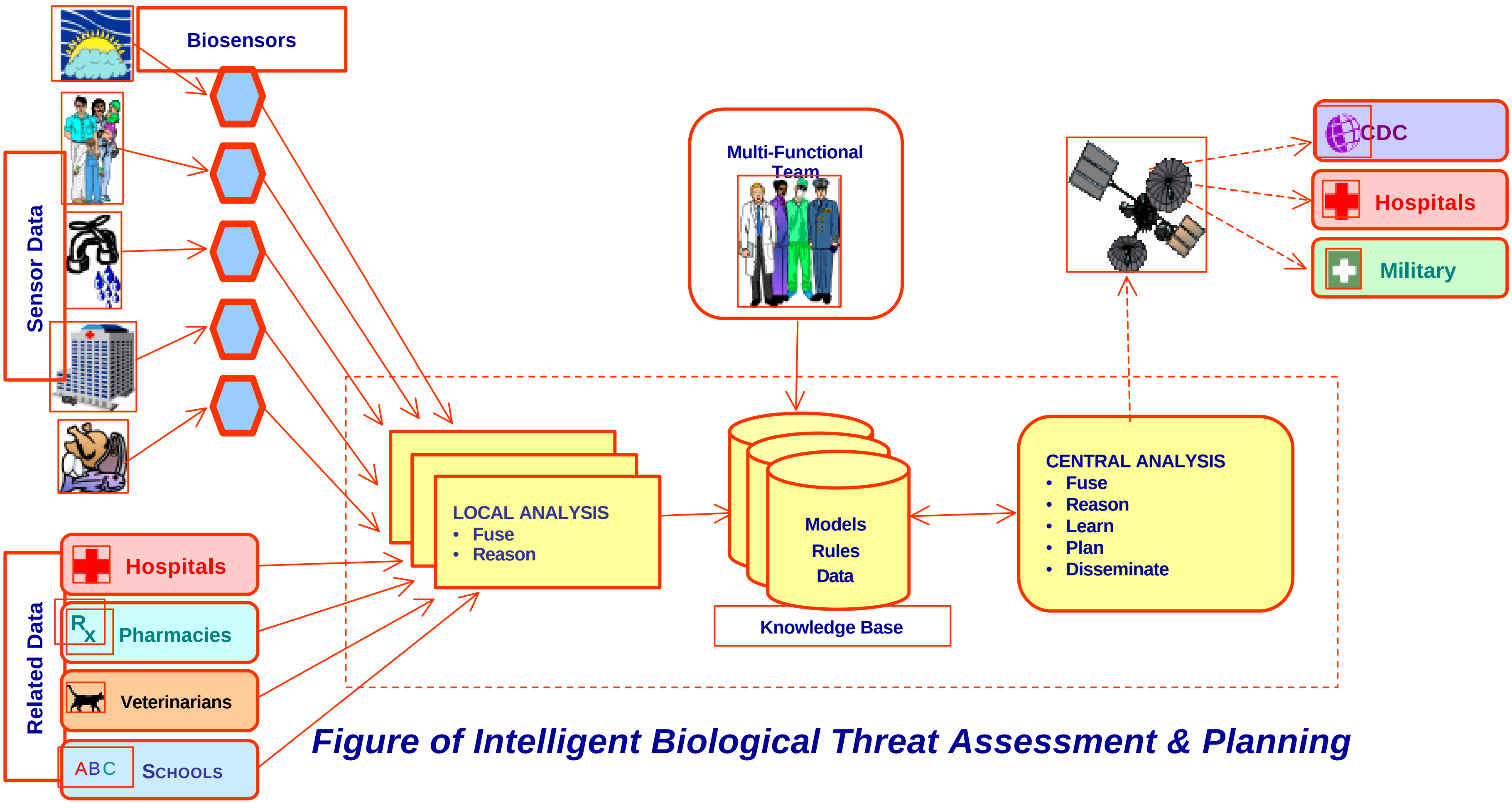
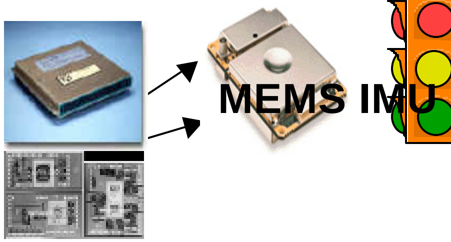


Figure of Intelligent Biological Threat Assessment & Planning

From DARPA MOSIS to OSD MEMS Foundry

Why MEMS? Possible Consumer Electronics

“XYZ on Chips” bio-sniff requires vacuum pump,
parallel sampling plastic ducts via MEMS



Maintenance “free” per season:

Robust MEMS for sensor platform integration

Interface Standardization requires Int’l Collaboration

Meetings regularly in MEMS and Chembio are needed to stimulate R/D.

•Standard Interfaces are required to encourage the volume production for the cost reduction of various Chembio detectors via optical, electrical & mechanical changes

•MEMS Foundry demanded for university R/D, similar to early MOSIS

•Government, Academia and Industry Cooperation for dozen Foundry:

•Heavy Activities exist at Special Purpose Applications R/D

•Commercial Applications are only limited by imaginations.

•Leverage Governmental Needs through grants etc.

•No specific effort in advancing MEMS, except few agencies.

New Era of Economic Boost via Commercial Applications:

•High g inertial motion guidance requires large proof size/mass ratio

•Generic approaches are capacitor, piezoelectricity, optics path changes

•Integration of GPS with IMG is missing for compact recreation and navigation usage

•Optical wavelength Switch for Communication

•Household CO and fire detection, and supermarket fish and meat freshness

CBTABS: Wash DC Testbed

Testbed must be "Alarm-On Always for All Weather":

Traffic Light Power-line System that adopts the non-intrusive DSP modem on 60 Hz carrier can solve the immense cost of City-wide infrastructure for both the (inductive) power supply (no need of battery replacement) and secured intra-inter-communication among local sensor suites!

Additional Communication Challenge remains: Circuit experts overcome

1. ***Source Codec issue***: High frequency High bandwidth Power modem,
2. ***Insertion loss issue***: Wireless Plug-in, Wireline plug-in, insertion via insulation skin induction for distortionless video BW:
3. ***Path Connectivity issue***: Non-interruptible Smart Bypass of Power Transformers and Inductor Coil blockage,
4. ***COTS Issue***: You get what you pay for: Cellular phone T/R, Pager, Police Radar Integration,
5. ***Jamming & Security Issue***: Distributed Security & Bandwidth Jamming

Metcalfe's O(N2) Law

Power Com Systems: *New Niche Smart Sensor Web Urban Surveillance Testbed* *Ph DThesis Pornchai Chanyagorn oob @ gwu. edu*

International Effort

•German Mannheim, MVV, offers 2.5Mbps Broadband via powerline, say, ***OFMA***
enormous cost for Cisco-like switch board hubs

•Israel Broadband Powerline Internet. M@in.net (www.mainnet-plc.com/home)
relative low cost/unit new housing

•Japan powerline meter reading ***monthly reading low bits no address, say TDMA***

New Niche: Smart Sensor Web Urban Surveillance

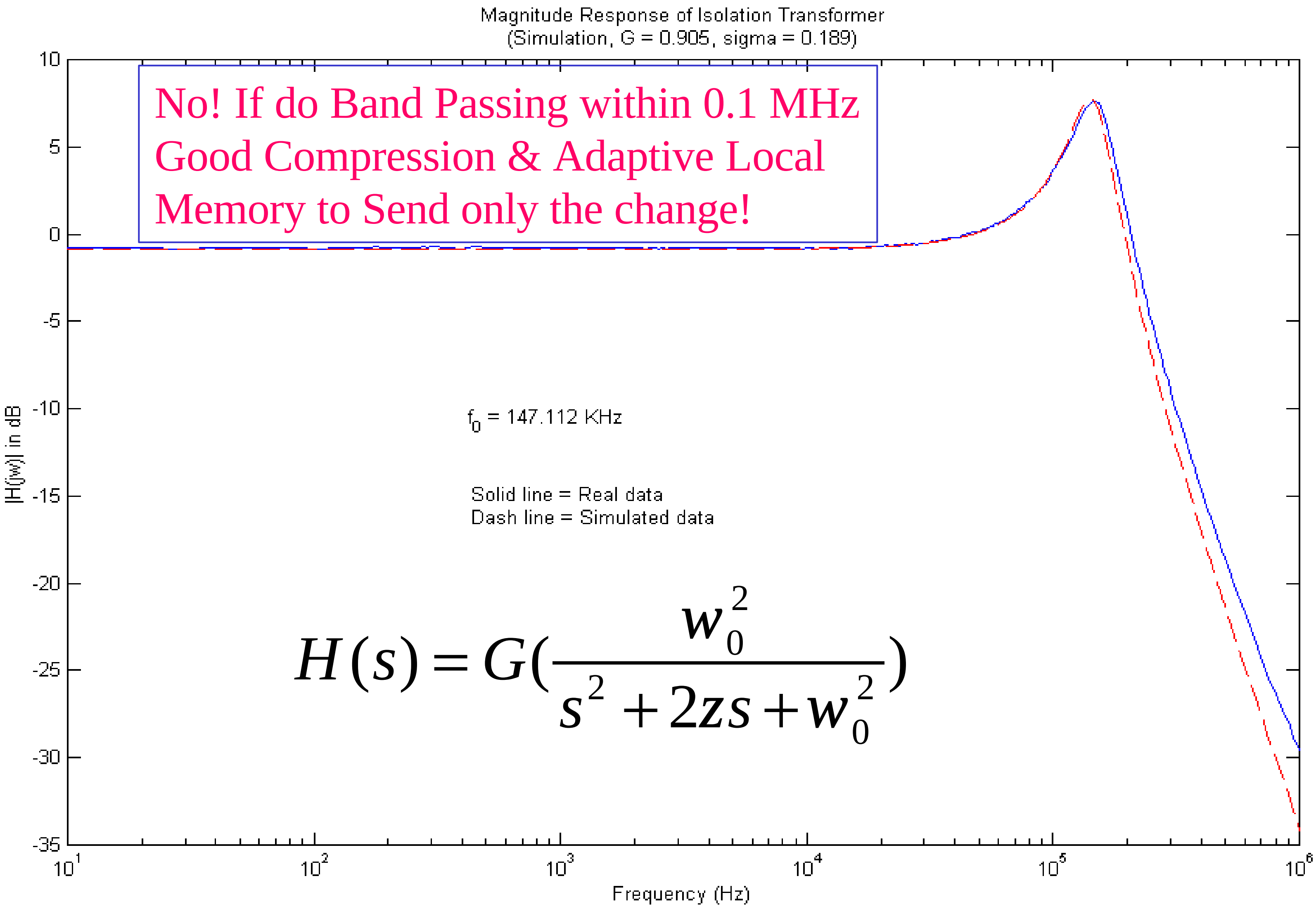
•***single user, e.g. owner, shopping complex, police, city government, no need IP***

•***N.sensors-to-One broadcasting requires some address-like coding for locality***

•***Smart Human Visual System (HVS) compression processing algorithm, CR: 2D to 1D (HVS Singularity Map) about 1000:1 16 kbps wireless SINCGARS radio***

•***Data survive short-distance channel environment of hostile Isolate Transformer (Ultra-Isolation transformer Model 17152, Topaz electronics, San Diego), Step-Up/Down Transformer(Step-down/up transformer, Archer electronics, USA) and Powerline (DC Power Co).***

Is the Transformer the road block?



No! If do Band Passing within 0.1 MHz
Good Compression & Adaptive Local
Memory to Send only the change!

$$H(s) = G\left(\frac{w_0^2}{s^2 + 2zs + w_0^2}\right)$$

CBTABS: Wash DC Testbed

Testbed must be "Alarm-On Always for All Weather" (AOAFAW):

Maturing CB Sensor Suites:

Ion Mobility Spectrometry (IMS);

Surface Acoustic Wave (SAW) change through molecular adsorbed polymer;

Optic-fiber UV-florescence-antibody sandwich;

Gold Powder hydrophilic-chain molecular-adsorbed electrical resistance change;

size distribution counting of virus, DNA Chips; Blood Diagnosis Board; etc.

Testbed Logistic Issues:

1.***Who*** else are qualified with street working experience to down select CB sensors maturing at different stages?

2. ***Where*** on the pole should the equipment be safely located ?

3. ***What kind*** of housing design for Sampling Concentration by Vacuum Pumping, Thermal Wind Diffuse Migration work at various meteorological Condition?

Real world application issues:

1. ***Minimizing*** **Scheduling**: : A Ph.D student assigned to each sensor to learn and to carry it over for monthly simulated and real street test experiments

2. Sampling Concentration: adaptive thresholding for individual FAR reduction,

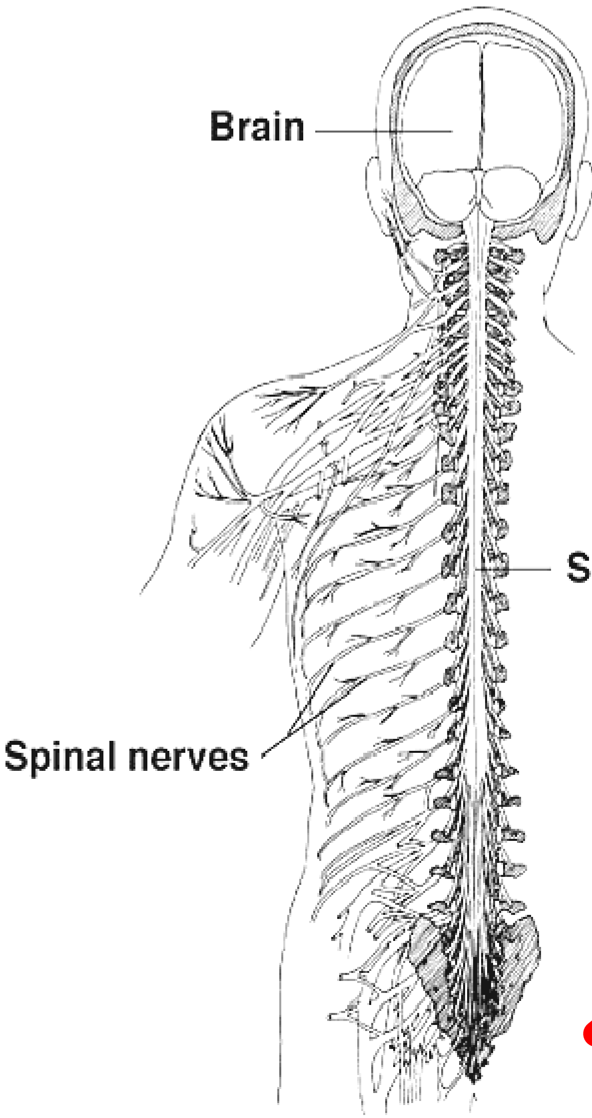
3. ***Sensor Suite Mutual Interaction***: Context priming PD enhancement

4. ***Network False Positive Reduction***: Heirarchical Intelligent Network Fusion for achieving 100% PD and zero% False Positive.

Working Hypothesis and Challenges

- Powerlines are full with unpredictable noise, e.g. thunder strikes, on & off, Mr. Lenz generates unwanted signals dissipating wires.
- Given smart bio-sensors feature-preserving HVS compression, our thinking must be different to de-scramble communication.
- MIQ™ of the combined (terminal-powerline) system (Szu, NIST Vol. 970 (Ed.Meystel & Messina), Aug. 2000 pp.383-398) must be redistributed not at the communication channel but toward the terminals, i.e. smarter sensors to utilize existed-buried dumb powerlines.
- How do we communicate without address?
  - Eco Sys.fishes birds animals via Rivers & Creeks under gravity
  - Bio Sys. complex synthesis via blood lymphoid nutrient systolic heart pump
- How do we solve the cocktail party effect?
  - Unsupervised Learning Neural Nets for Blind Sources Separation

Learning communication without addresses from BioSystem :Neural sensors, spinal cord, brain,



Smart Sensors = muscle tactile nerves

Powerline = Spinal cord & Wireline
Blood & Wireless Lymphoid

Smart terminal= Cortex of Brain

Given dumb communication

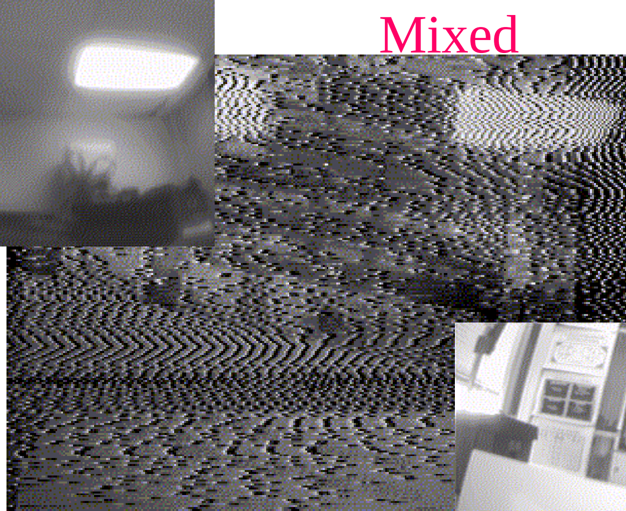
No more dumb sensors

No more dumb terminals

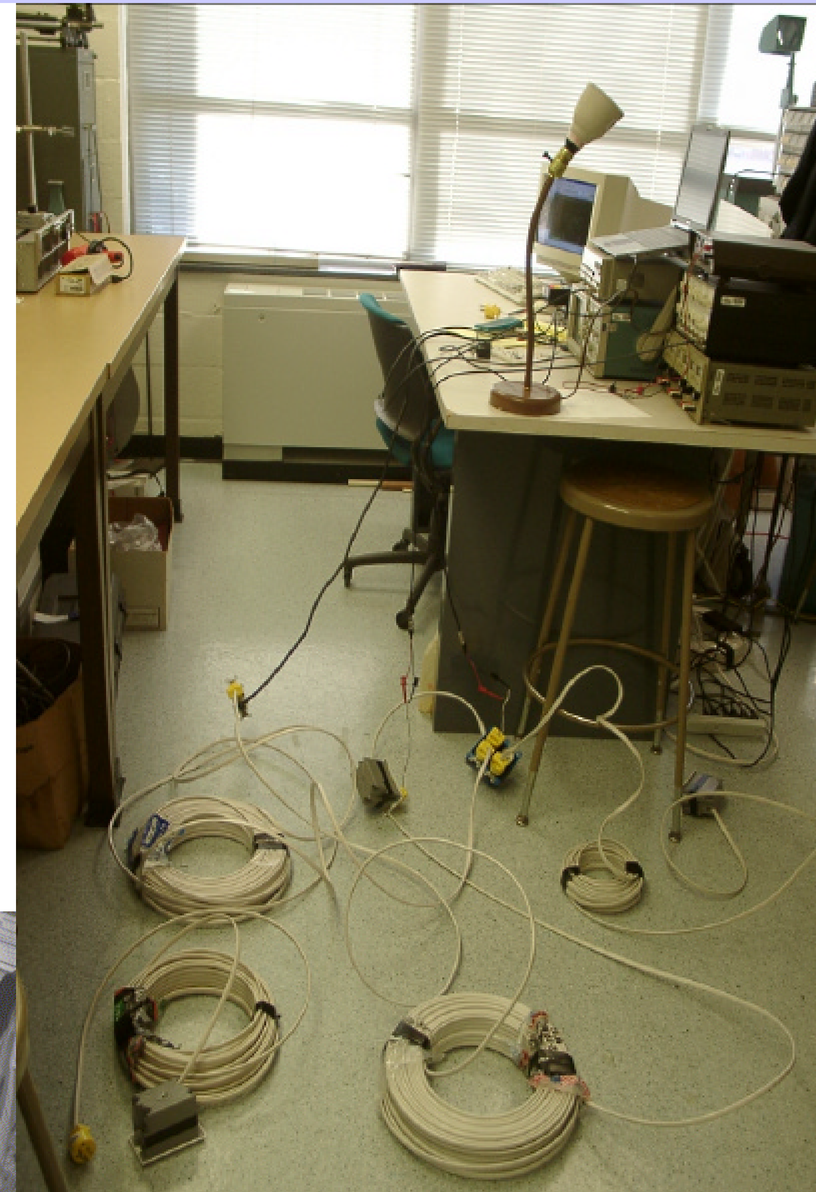
Smart Sensor Web Testbed Experiments

- The test experiments will be set in *simple but real* powerline environment:
  - Begin with one user in *single house* environment
  - The powerline has only 2 wires come in, then separated to two branches with p-phase difference for the household utility and lights respectively.
  - Measure the two branch transmission channel characteristics
  - Matlab™ tool to design 2 smart video inputs from the up stair and down stair power plugs finding themselves to a PC power plug somewhere in the house.
- Experiments with the transformers, the bandwidth of the channel will be between 50kHz to 150kHz.
- 1bit per Hz (Phase Shift Key) to 1 Byte per Hertz (fiber-optics)

Experiments at Digital Media RF Laboratory

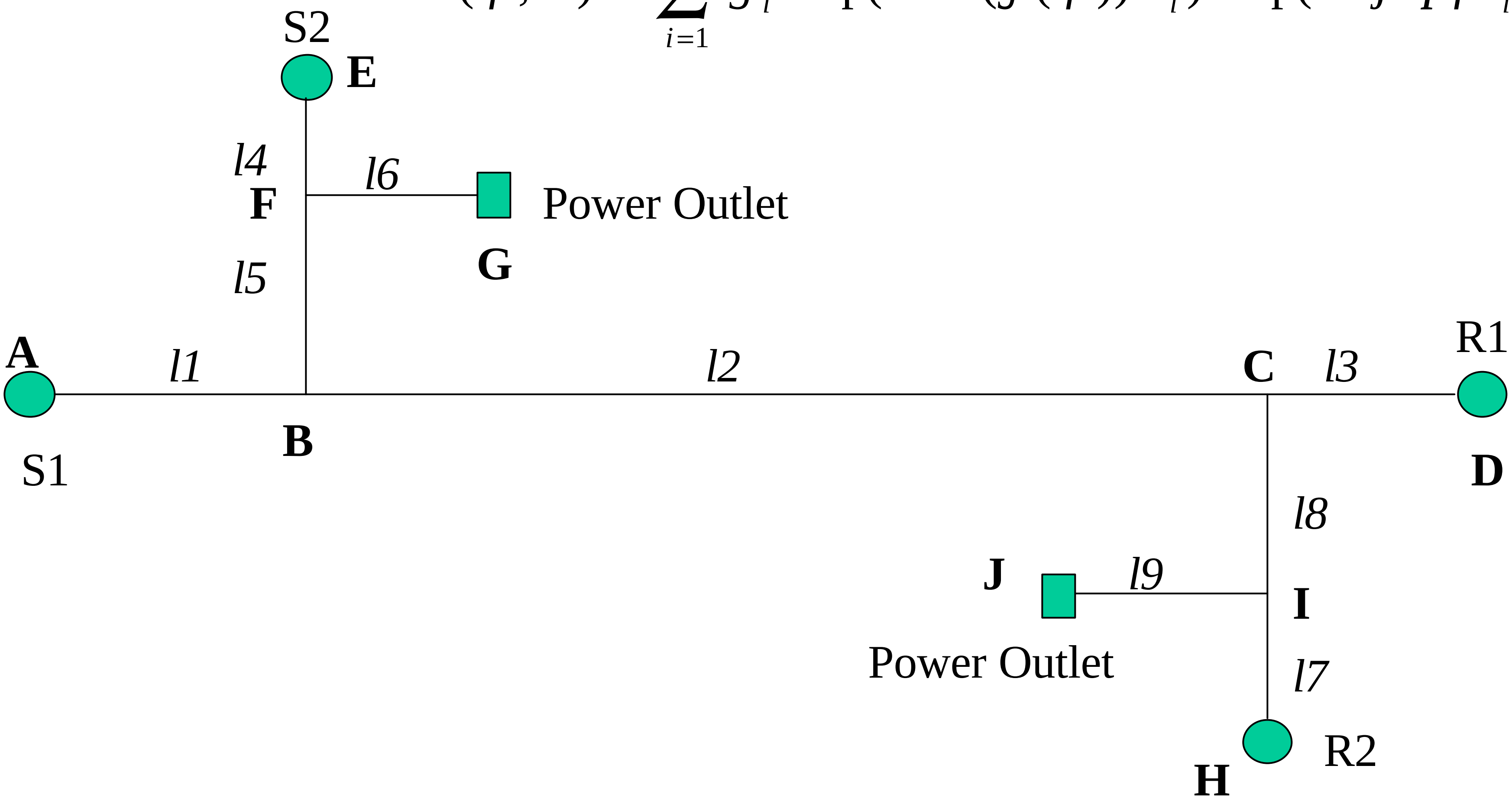


Commercial Products: SeaView

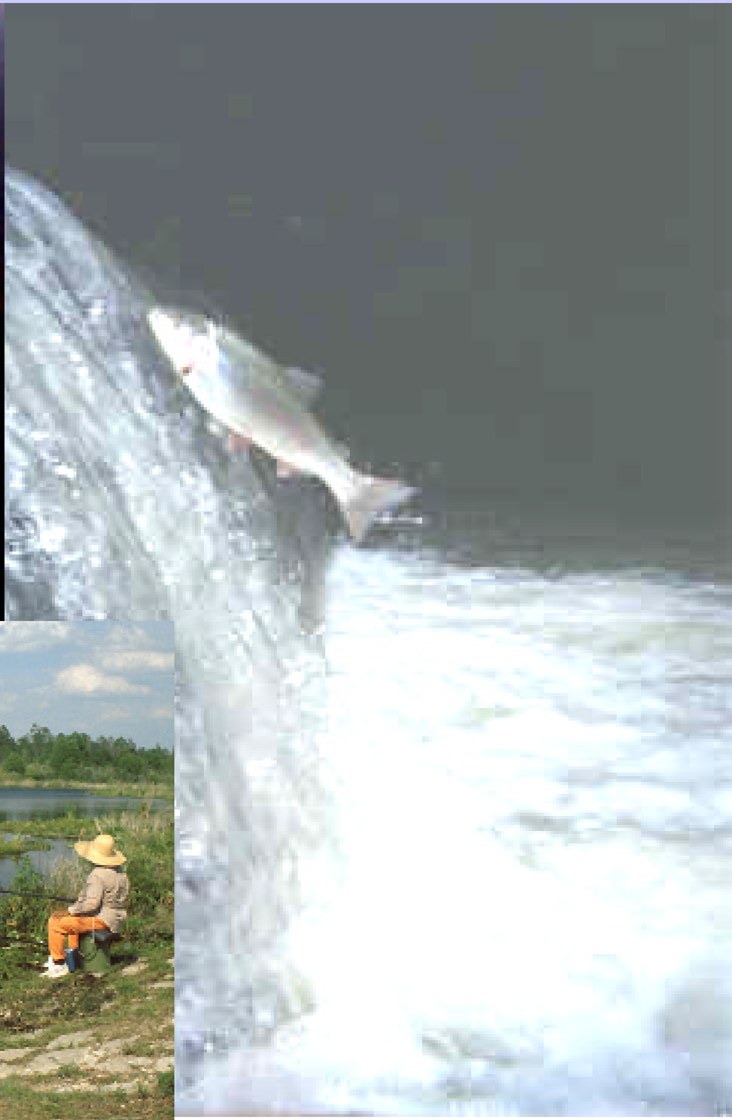


Powerline Topology and its model in High Frequency Range (> 0.5 MHz)

$$H(f,d)=\sum_{i=1}^{N} g_i . \exp(-\Re(g(f))d_i) . \exp(-j2pft_i)$$



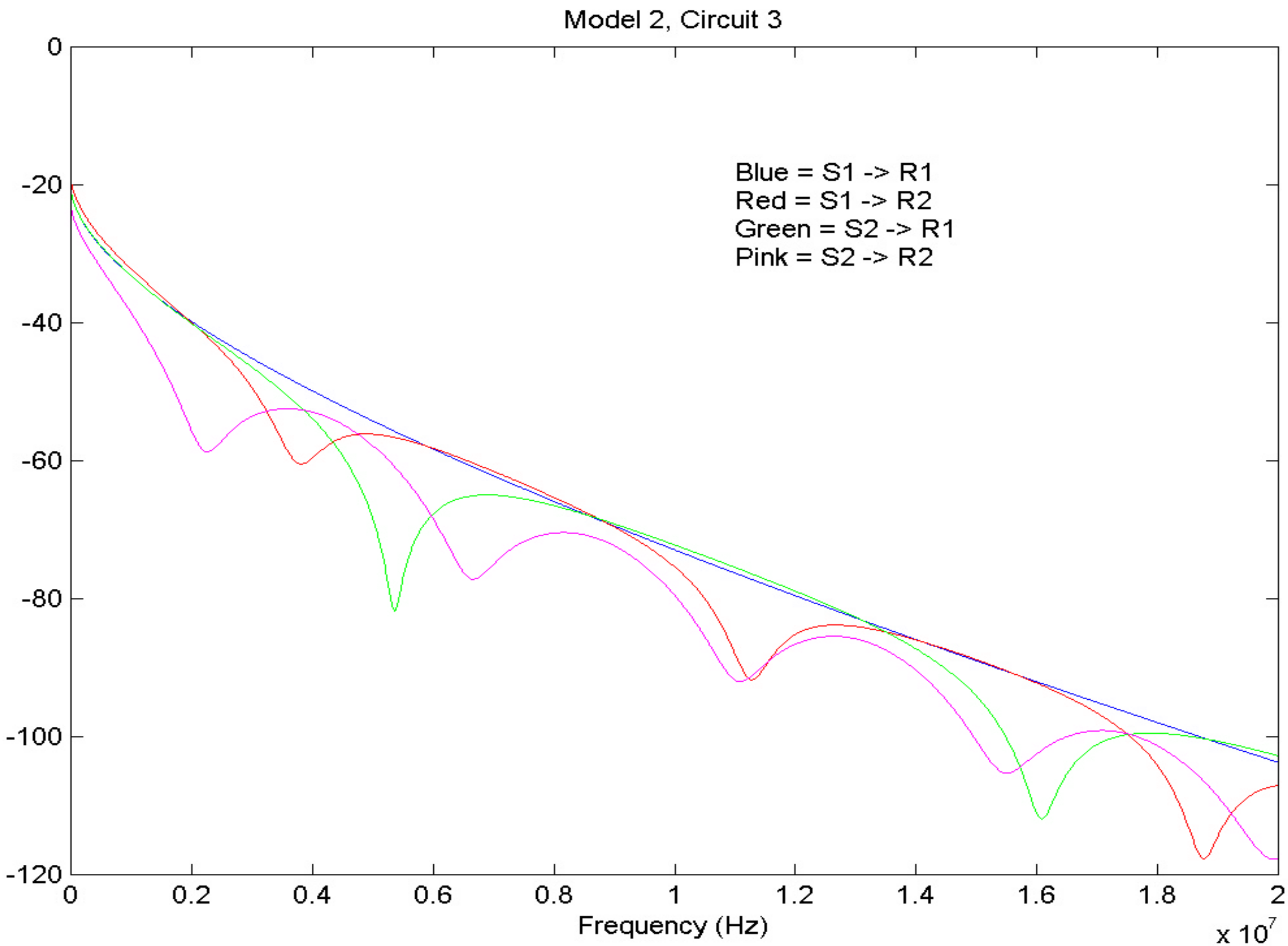
Learning the communication without addresses from EcoSystem: Rivers under the gravity, Fishes, Animals



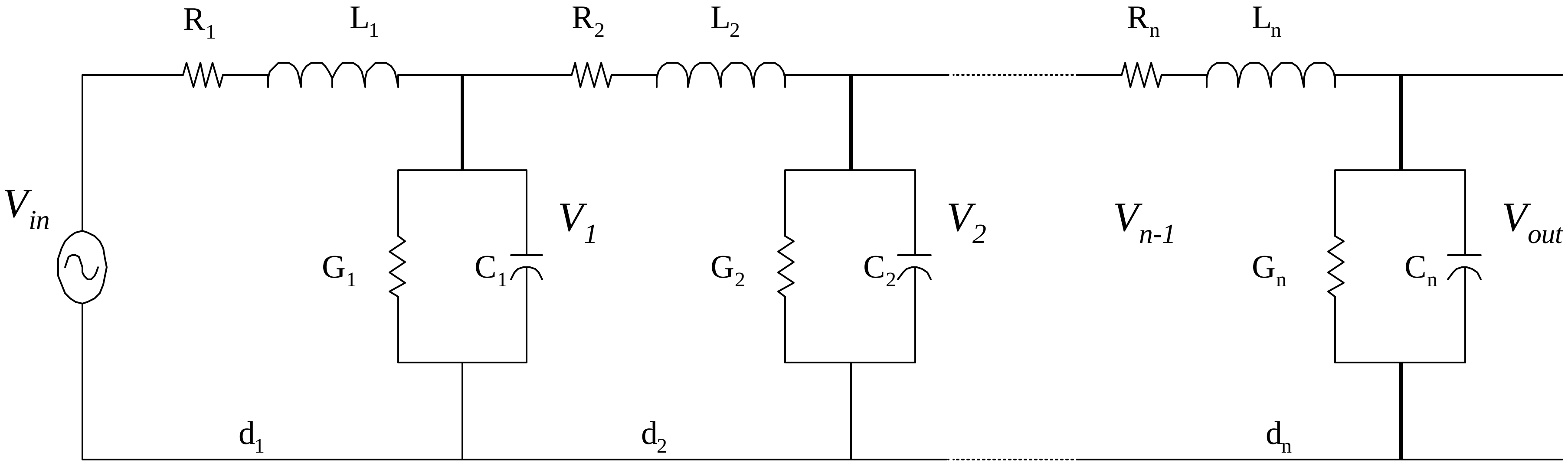
Fish Man Fishing = Identify Address and Correct Information Pass

Information = Fish

Magnitude Response of Powerline



Power Line Model for Low Frequency Range



$$\frac{V_{out}}{V_{in}} = \exp(-gd) \Rightarrow \frac{V_{in}}{V_{out}} = \exp(gd) \Rightarrow gd = r_1 d_1 + g_2 d_2 + \ldots + r_n d_n$$

$$\frac{V_{in}}{V_{out}} = \frac{V_{in}}{V_1} \cdot \frac{V_1}{V_2} \cdots \frac{V_{n-1}}{V_{out}}$$

$$g_i = \sqrt{(R_i + jwL_i)(G_i + jwC_i)}$$

$$i = 1 \ldots n$$

We can find the PLC system transfer function

Using histogram of the sparseness of binary data representation (finite alphabets)

$$\boldsymbol{x}(k) = \boldsymbol{a}^{\boldsymbol{T}} \boldsymbol{s}(k)$$

$$a_{i3} = (\hat{c}_{i2} - \hat{c}_{i1}) / 2$$

$$a_{i2} = \left(\hat{c}_{i3} - \hat{c}_{i1}\right) / 2$$

$$a_{i1} = -\left(\hat{c}_{i2} + \hat{c}_{i3}\right) / 2$$

We measure PLC transfer function the BSS is no longer blind

$$\boldsymbol{c} = \boldsymbol{T}\boldsymbol{a}$$

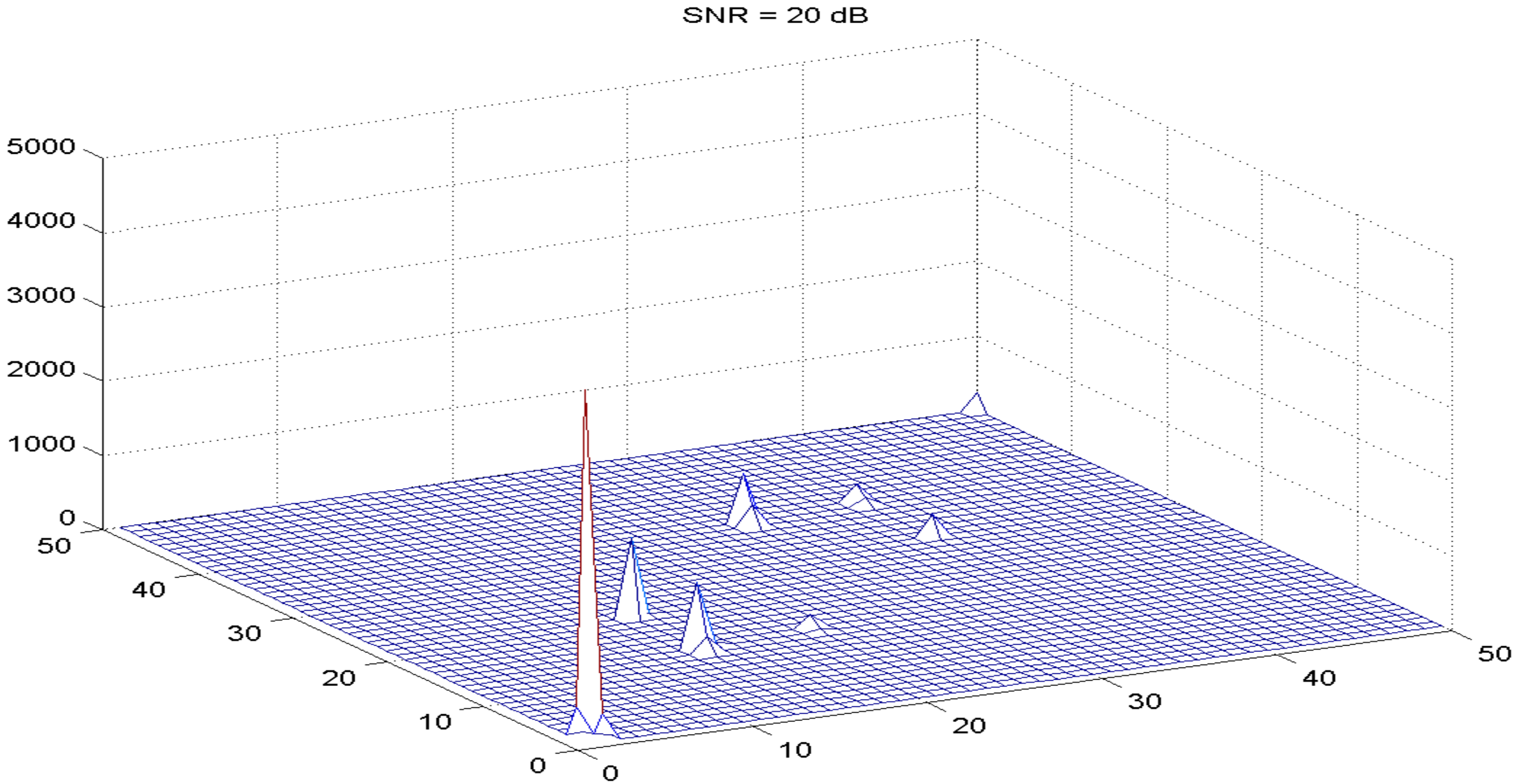
$$\mathbf{T} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & -1 \\ 1 & -1 & 1 \\ 1 & -1 & -1 \\ -1 & 1 & 1 \\ -1 & 1 & -1 \\ -1 & -1 & 1 \\ -1 & -1 & -1 \end{bmatrix} = [row - vectors - t's1]$$

$$\hat{\mathbf{s}}^{(i)}(k) = \min_{t_j} \left\| x^{(i)}(k) - (\hat{\mathbf{a}}_i, \mathbf{t}_j) \right\|^2$$

2D Histogram shows the number of sources

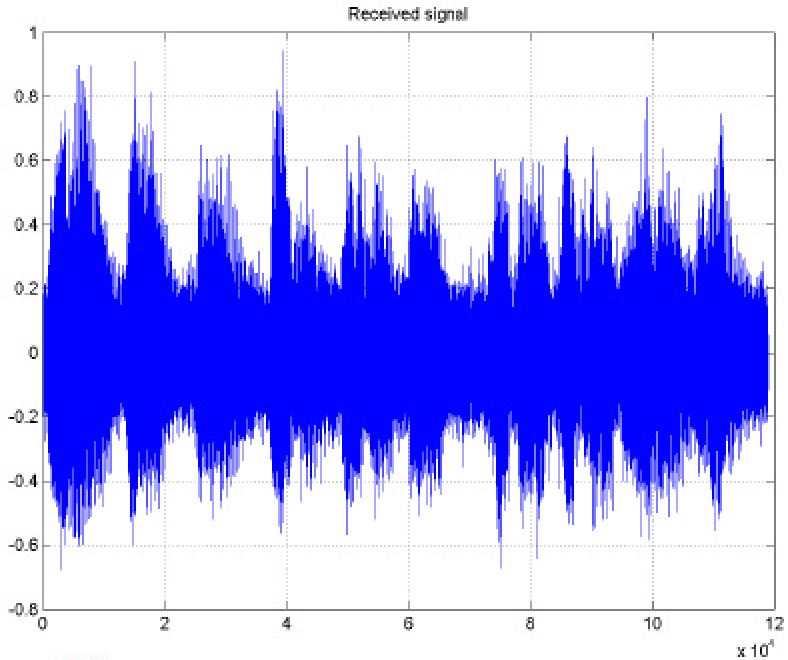
- By using 2 plug-outs

$$P\left(\boldsymbol{x}(k)=\boldsymbol{X}\right)=\frac{1}{\sqrt{2p\,s}}\sum_{i=1}^{M}\exp\left\{-\frac{1}{2s^{2}}\left(\boldsymbol{x}(k)-\boldsymbol{c}_i\right)^T\left(\boldsymbol{x}(k)-\boldsymbol{c}_i\right)\right\}P_i$$

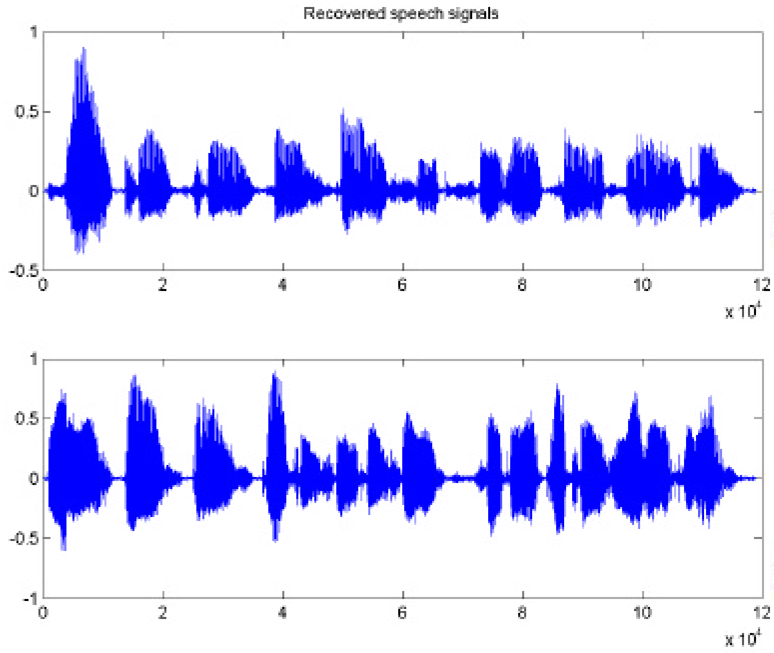


De-Mixed speech signals simulation

- Received signal from PL model

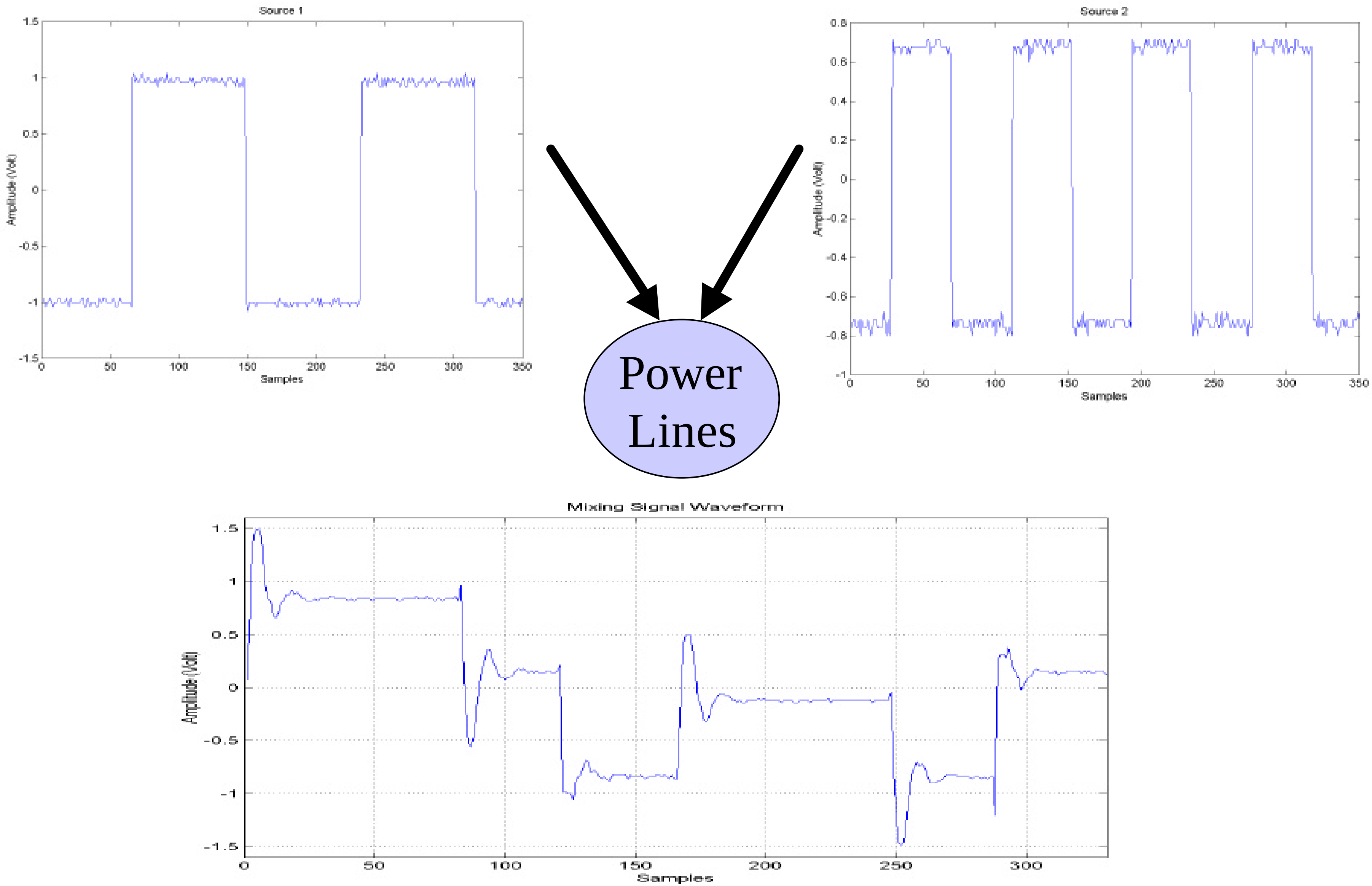


- Recovered speech signals



Note: Click on the speaker icons to hear the speeches

Mixed Signal from Real Experiments



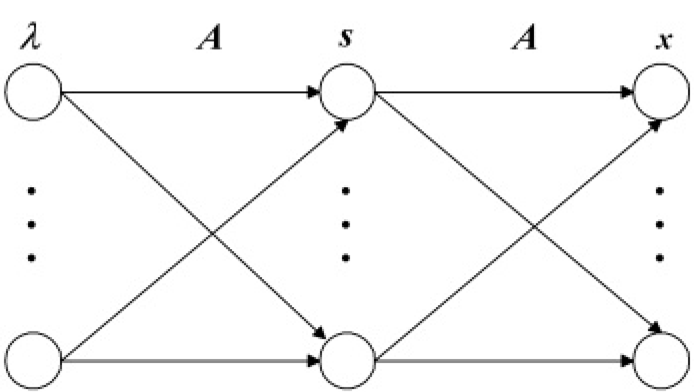
How to exploit/prevent Leakage through PL?

- Physics dictates reaction to every action:Switching on/off nonlinear inductive load will generate Lenz's transients on the PL in principle.
- The opportunity becomes real in view of our smart algorithm to be able to deliberately send signals without addresses through PL and de-mix them.
- Probably the same methodology might be applied to detect how many PCs are active in the network

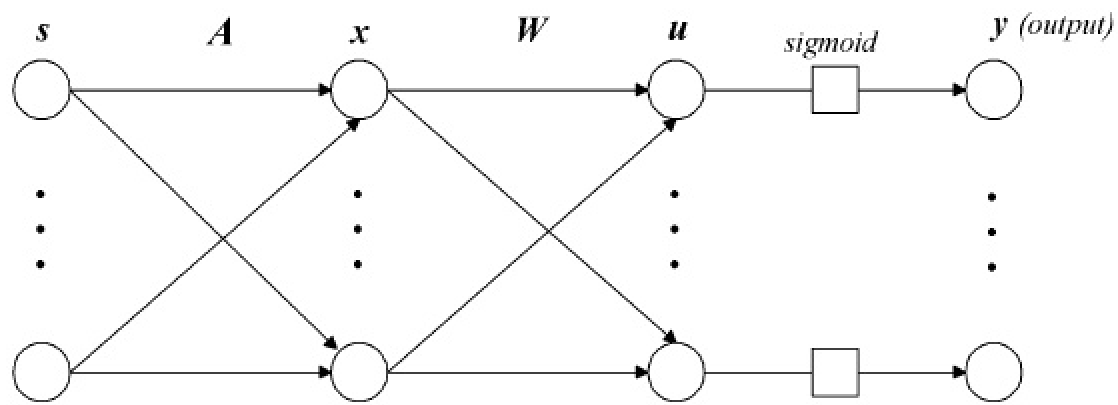
What are the smart algorithms to exploit the Leakage through PowerLine?

Given Blind Source Separation Data Mixture X(t) = find [A?] S(t)?

- Sparse Binary noisy signal is finite alphabet communication like Morse code is not really blind if we use more pick-ups from PL for denoise.
- Analog transient noisy signals we use the real-time a-priori MaxEnt Lagrange Constraint NN by Szu in 1997 or the batch mode by a-posteriori MaxEnt Bell Sejnowski Amari Oja in 1997



LCNN



BSAO NN

Smart consensus solves both the Curse of Dimensionality and the false positive alarm rate for world C-B MEMS R/D:

Collaboration Issues:

Bio Med Student Education--Scholarship for students
Visiting Faculty Exchange Students--Headquarter, Housing
Monthly Workshop--Logistic Support
Interactive Knowledge Deposition Web Page--Storage, Public, and Private Pages

R/D Issues: Implement Testbed on Year 1 to Identify Full Scale Challenges

Wireless& Wireline-- High Frequency Smart Powerline Modem for High BW, RF Surveillance for All Weather**,** Police Radar Direction Finding, digital Radar for Communication & SAR,...
Nonlinear Blind Source De-mixing--NL Blind Source De-mixing,
Anti-Metcalfe's Law: the power complexity of network increase as NxN square law as node N increases.**----**
OSD/Smart Sensor Web: Jasper Lupo said: "Learn the difference (from the consensus) & send (only the difference)", reducing to Order(N).

Questions & Comments

Jasper Lupo EETimesOEG20010423S0110.htm

"Jasper Lupo believes that a smart-sensor web
can monitor street traffic via MEMS sensors."--R.C. Johnson
EETimes May 9, 2001

For Real Time Demo Video Via Powerline:
cf. Http://www.student.seas.gwu.edu/~dmlab/

Smart sensors extend Web scale By R. Colin Johnson EE Times (May 9 2001, submitted 04/26/01, 10:46 a.m. EST)

eep in the bunkers of the Office of Naval Research, physicist Jasper Lupo recently demonstrated how his "smart-sensor web" sidesteps the seemingly insurmountable Metcalfe's Law with neural learning. Comprised of thousands of wireless microelectromechanical systems (MEMS), the smart-sensor web

manages increasing numbers of network nodes with only a linear increase in overhead, thereby sidestepping Metcalfe's geometric-explosion "law."

"I wouldn't say our smart-sensor web beats Metcalfe's Law, because even Metcalfe says his law is not really a law, but our program has demonstrated how smart network nodes enable you to go from a small network to a large one without overwhelming integration problems," said Lupo. Metcalfe claimed that the wild success of the Internet's World Wide Web results from his law: that the value of a network increases exponentially with its number of users. The "value" here means that network traffic and management overhead grow exponentially with each added node.

While that may be great for the budding Internet service providers that make money off servicing nodes, such exponential growth is too fast for the deployment of battlefield networks. "We want to provide exquisite situational information to the individual soldier, but today we are restricted to the battalion level. Without smart sensors, it's just too hard for smaller groups, like companies, platoons or squads, to digest all the incoming information," said Lupo.

For instance, satellite imagery can be combined with video feeds from drone aircraft to almost instantaneously build up a three-dimensional wire-frame virtual-reality simulation of a previously unknown battlefield. Then, as ground troops and vehicles approach, each with their own embedded sensors, the "textures" of the wire frame can be "painted" with live images from the live objects in the field. Soldiers thus can practice missions in virtual reality before actually performing them, an invention that Lupo said has "excited" the foot soldiers who have helped test it. "We want to make every soldier, every vehicle, every aircraft-everything-a smart sensor node on the battlefield network. Jasper Lupo, a physicist in the Office of Naval Research, believes that a smart-sensor web can monitor street traffic via MEMS sensors.

"With advanced wireless technologies and MEMS sensors we can do that, but to integrate the network we had to take a lesson from neural networks and put memory alongside processing capabilities in each node," said Lupo.

MEMS provides the enabling technology for drone aircraft to drop thousands of wireless sensors onto an active battlefield, creating an instant network. But the amount of data streaming in from them would be impossible to digest in real-time by a central computer.

In a nutshell, Lupo discovered how to sidestep Metcalfe's Law for battlefield sensor networks by wiring them the way the spinal cord sends information up to the human brain from the eyes, ears, nose, tongue and skin-that is, by placing next to each sensor a neural-network memory element that "learns" what is normal.

Since the network manager (or brain, in the case of a human) also has a copy of what is normal, it can refer to its copy, rather than congest the network with redundant reports.

That's possible because the smart sensors only transmit updates to the manager's copy when something abnormal happens.

In this manner, neural learning exponentially decreases the amount of network traffic and management overhead, thereby canceling out Metcalfe's exponential expansion law-and resulting in only linear overhead increases for each added node.

For instance, consider temperature. "Normal" for temperature would follow both the time of day and the time of year-cooler in the evenings, warmer during the day, cooler yet in the winter, warmer yet during the summer. With a neural network learning what the normal temperature is, the sensor need only transmit reports of out-of-bounds temperatures-the "delta"-thereby greatly decreasing the network traffic that is produced compared with a 24/7 continuous stream of reports.

According to neural researchers, if we wired our spinal cord the way that we do our computer networks, then no one would be able to hit a 100-mph fastball; we wouldn't have enough bandwidth. But by adding neural learning to make smart sensors, the network can get by with drastically reduced bandwidth, in much the same way as a hitter can slug a fastball.

The current program ($9 million during 2001) ends in October, but its eventual aim is to overlay five smart webs on the battlefield for images, weather, weapons, simulations and integration.

Civilian uses, too

However, just as the Internet was born of the military's ArpaNet, so has Lupo already envisioned a future for the smart-sensor web in the commercial sector. By melding single-chip MEMS sensors with the smart-sensor web for domestic neighborhood monitoring, almost any chemical or biological substance could be tracked in real-time-from pollen counts to natural-gas leaks and even terrorist-released contaminants.

The Office of Naval Research proposes that the government deepen the U.S. information infrastructure by installing a "chemical-lab-on-a-chip" in every traffic light in the United States and interconnecting them into a digital subscriber line network riding atop the ac lines. DSLs use high-frequency digital signal processors to multiplex data over normal twisted-pair telephone lines.

That approach works equally well for dual use of electric power lines in city traffic lights for always-on communication with MEMS sensors, said Lupo. With a national traffic-light network installed, civil and military authorities nationwide could monitor the atmospheric conditions on any street corner in America as easily as they monitor its visual appearance from satellites today.

"It's not just traffic lights either," noted Lupo. "Eventually we will probably update our building codes to include, say, a smart lightning rod on the roof."

It's already possible, said Lupo, to "build a smart MEMS weather station in the space of a cubic millimeter." In his view, "it will become increasingly easy to put smart sensors into all kinds of new construction."